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TO: Daniel C. Hill, Esq., Hill Law

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SUBJECT: **Technical Review of MODFLOW Model and Associated Mounding Analysis Presented in Support of the Proposed Hanover Weston Development, Weston, Massachusetts**

McDonald Morrissey Associates, LLC (MMA) is providing this memorandum to summarize the outcome of our review of the MODFLOW numerical groundwater flow model created by Sanborn Head Associates, Inc. (SHA), in support of the proposed Hanover Weston development in Weston, Massachusetts. Information considered by MMA while conducting the review included the following:

- *Hydrogeologic Evaluation Report, Hanover Weston, Weston, Massachusetts*, dated March 19, 2020, authored by Sanborn Head Associates, Inc. (referred to herein as the SHA Hydrogeo Report);

- *Mounding Analysis Documentation Package, Hanover Weston, Weston, Massachusetts*, dated October 5, 2020;

- Electronic model input and output files contained within a .zip format archive entitled *MODFLOW Files_zip*, transmitted via email November 4, 2020 by Vern Kokosa of Sanborn Head Associates, Inc.; and

- *Stormwater Management Report*, revised date October 30, 2020, authored by Tetra Tech, Inc. (referred to herein as the Tetra Tech Stormwater Report).

MMA understands the objective behind developing and applying the MODFLOW model was to estimate the maximum amount of hydraulic mounding that may occur under proposed, post-development conditions, as constrained by applicable Massachusetts Department of Environmental Protection (MassDEP) guidelines for conducting assessments of this type[1]. Based on our review, it is MMA's opinion that the

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[1] *Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal*, Commonwealth of Massachusetts, Department of Environmental Protection, Division of Watershed Permitting, Revised July 2018.

model does not address this objective and is generally an unreliable tool for estimating mounding due to the following issues:

1. Physical attributes of the model, including vertical dimensions, are not well supported by or consistent with available information and/or data.

2. The modeled groundwater flow direction under pre-development conditions does not agree with available data and/or the basic conceptualization of the local groundwater system.

3. The simulated rate of discharge within the primary wastewater disposal area is approximately 70% of the design flow rate, as opposed to the applicable MassDEP guideline value of 80% of the design rate. A similar, low-biased error may also influence the modeled rates for key proposed stormwater infiltration features.

4. Alternative modeling performed by MMA suggests the model underestimates groundwater mounding potential.

The following technical discussion elaborates on these points by presenting our observations of model issues organized by category:

Category 1

MMA defines Category 1 issues as being associated with aspects of the model that are erroneous or conceptually inconsistent with available information and/or data. Furthermore, MMA views these issues as having adequate available information to support adjustment of the model to assess effects on mounding estimates. MMA has developed and implemented an alternative MODFLOW model for this purpose.

Issue 1-A: Overstated vertical thickness of unconsolidated sediments, such as sand and gravel or glacial till, that is not supported by available information.

Vertical thickness of the saturated sediments above bedrock is a critical model specification when simulating hydraulic mounding potential, as hydraulic responses predicted by the model can be sensitive to the representation of aquifer transmissivity[2], where transmissivity is defined as the product of horizontal hydraulic conductivity and saturated thickness. Thus, for a mathematical model to produce reasonable mounding estimates, thicknesses should be generally consistent with available site information and field data, such as boring depths. If extrapolating beyond such information, a reasonable basis for doing so should be identified.

According to the SHA Hydrogeo Report, the deepest subsurface exploration performed was the boring identified as SH-5, which was advanced to a depth of 22 feet

[2] *Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins*, United States Geological Survey Scientific Investigations Report 2010-5102.

below ground surface. Logs provided for several other borings and test pits identify refusal (i.e., physical obstruction such as bedrock or lodgement till) preventing deeper penetration) being encountered as shallow as 6.6 feet below ground surface.

In the vertical dimension, the MODFLOW model described by the SHA Hydrogeo Report contains 5 layers, all having uniform specified thicknesses of 10 feet. At 50 feet in sum, the total aquifer thickness represented within the model exceeds the maximum observed sediment thickness by more than a factor of 2.

The noted discrepancy between observed saturated thickness (less than or approximately equal to 22 feet) and modeled thickness (50 feet) is not discussed or justified in the information reviewed by MMA. It is also biased in a direction that would suggest the model overstates aquifer transmissivities and therefore may underestimate mounding heights, potentially leading to non-conservative conclusions.

Issue 1-B: Overstated extent of higher permeability sand-and-gravel deposits that is not supported by available information.

Similar to Issue 1-A, general consistency between actual and modeled aquifer properties, which often differ with interpreted soil/material type, is critical to producing reasonable estimates of hydraulic mounding. As described within the SHA Hydrogeo Report, the hydraulic conductivity value assigned to the "sand and gravel" soils exceeds the value assigned to the "glacial till" soils by a factor of 10 (i.e., 100 feet per day versus 10 feet per day, respectively). Though these values appear to be conservative assumptions relative to available data, the areal extents of the zones could greatly influence model-estimated mounding (e.g., if the extent of the "sand and gravel" soils is exaggerated, transmissivity may be locally overstated, resulting in underestimated mounding).

According to the exploration logs provided in the SHA Hydrogeo Report, the higher hydraulic conductivity "sand and gravel" soils were identified in two test pits (SH-TP-1 and SH-TP-7) and one boring (SH-5) located in the vicinity of the proposed primary wastewater disposal area. At these locations, the maximum observed thickness of the "sand and gravel" soil type was limited to approximately 8.5 feet (SH-TP-7). Comparatively, the model represents the "sand and gravel" soils as being 40 feet thick in this area and extending over more than half of the areal extent of the model domain.

As is the case with Issue 1-A, this discrepancy creates an overstated aquifer transmissivity over a portion of the model domain, which may cause the model to underestimate mounding heights.

Issue 1-C: Unsupported and conceptually inconsistent lateral boundary conditions

Boundary conditions strongly influence the directions and rates of simulated groundwater flow within a model; therefore, it is important that they are designed based on a robust conceptualization of the actual groundwater system. Relative to the vicinity of the proposed development, basic hydrologic and hydrogeologic principles suggest groundwater flow directions are influenced by interaction with local surface water features (i.e., the stream and wetland complex) and recharge derived from infiltrating precipitation. Furthermore, groundwater elevations measured within monitoring wells and reported within the SHA Hydrogeo Report suggest a generalized west-northwest (WNW) to east-southeast (ESE) groundwater flow direction persists under pre-development conditions.

Curiously, the boundary conditions used in the model described by the SHA Hydrogeo Report result in a simulated groundwater flow direction oriented roughly from south to north, which is very different from the WNW to ESE flow direction interpreted from field data. The eastern wetland area is not represented within the model, which precludes using the model to estimate differences in down-gradient groundwater velocities or discharge rates in this area. No explanation is provided for the selection of the boundary conditions, including ignoring the wetland and stream complex, nor is an explanation provided for why the model appears to differ significantly from a model-independent interpretation of groundwater flow direction based on monitoring well water levels (i.e., refer to *Groundwater Contour Plan (Conditions on March 16, 2020)*, identified as Sheet Number 6 from the SHA Hydrogeo Report).

Issue 1-D: Undocumented model calibration process, and inadequate resultant ambient flow simulation result

The SHA Hydrogeo Report refers to performing a calibration of the MODFLOW model; however, no detail on the approach, supporting data, or results is provided. It is MMA's understanding that boundary conditions were the focus of the calibration effort[3]; however, as noted in the discussion of Issue 1-C, the resultant boundary conditions produce an unrealistic and unsupported groundwater flow gradients and direction. Thus, the calibration does not appear to have been successful. Lacking successful calibration, the model is not supported as a reasonable representation of pre-development conditions, nor can it be viewed as a reasonable basis for estimating post-development changes.

Issue 1-E: Erroneously low wastewater disposal area flow rate specification

The following statement is extracted from pages 8 and 9 of the SHA Hydrogeo Report:

> *"The groundwater mounding analyses were run in a transient flow condition for 90 days at 80 percent of the design flow rate in accordance with MassDEP's Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal revised July 2018."*

Based on this report, the proposed design flow rate for the primary wastewater disposal area is stated to be 38,000 gallons per day. At 80 percent, the simulated flow rate for this area should be 30,400 gallons per day during active periods representative of post-development conditions. However, based on an assessment of the model files

[3] Confirmed via email by Vern Kokosa of Sanborn Head Associates, Inc., November 11, 2020.

provided to MMA, the simulated flow rate during these periods appears to be slightly less than 26,500 gallons per day or roughly 70% of the proposed design rate.

This apparently erroneous input represents an inconsistency with the MassDEP guidelines referenced within the SHA Hydrogeo Report. Furthermore, it is particularly problematic relative to the model objective in that lower modeled flow rates translate to less significant mounding and more potential bias toward non-conservative conclusions (i.e., the lower specified flow rate at the primary wastewater disposal area results in less mounding and a lower maximum simulated mounding height).

It is important to note that MMA's review focused on simulations representative of the proposed primary wastewater disposal area. It is unknown if a similar error is present in simulations dedicated to the proposed reserve wastewater disposal area.

Alternative Modeling to Assess Category 1 Issues

MMA created an alternative MODFLOW model to assess the cumulative effect that Category 1 issues, described above, have on mounding estimates. Other issues, including the Category 2 issues discussed in later sections, were not addressed due to inadequate supporting information. For this reason, the alternative MODFLOW modeling assessment is useful in generally demonstrating the sensitivity of model results to a select group of issues identified via MMA's review, but it should not be viewed as a comprehensive replacement or refinement for/to conclusions presented within the SHA Hydrogeo Report.

MMA addressed issues 1-A through 1-E using the following process:

- The vertical thickness of the model was adjusted and applied to a redesigned finite-difference grid using local high-resolution topographic elevation data (i.e., LIDAR)[4] to define the top of the model and the test pit and boring log information contained within the SHA Hydrogeo Report to define the bottom of the model.

- Test pit and boring log information was used to support adjustment of the simulated extents of the "sand and gravel" and "glacial till" soils.

- In addition to developing a revised no-flow boundary at the bottom of the model domain, as noted above, a new set of perimeter boundary conditions was developed to be consistent with the following conceptualization of key local system characteristics:

[4] MassGIS LIDAR terrain data. https://docs.digital.mass.gov/dataset/massgis-data-lidar-terrain-data

- Whereas the primary local source of groundwater is precipitation recharge, the primary local sink (i.e., discharge mechanism) for groundwater is outflow to the eastern stream and wetland complex area. Since a reasonable approximation of the controlling elevation of the wetland area can be derived from LIDAR data, it is reasonable to represent this area as a head-dependent boundary using the MODFLOW Drain (DRN) Package.

- Smaller exchanges of groundwater and surface water are possible within the section of the stream located to the north. Stream elevations can be approximated based on LIDAR data; therefore, it is reasonable to represent the section of the stream draining to the wetland area as a head-dependent boundary using the MODFLOW General Head Boundary (GHB) Package.

- It is reasonable and conservative relative to mounding potential to assume a groundwater divide coincides with the position of the sub-basin divide to located to the west. Assuming the position of the groundwater divide remains static, it is reasonable to treat this area as a no-flow boundary in MODFLOW.

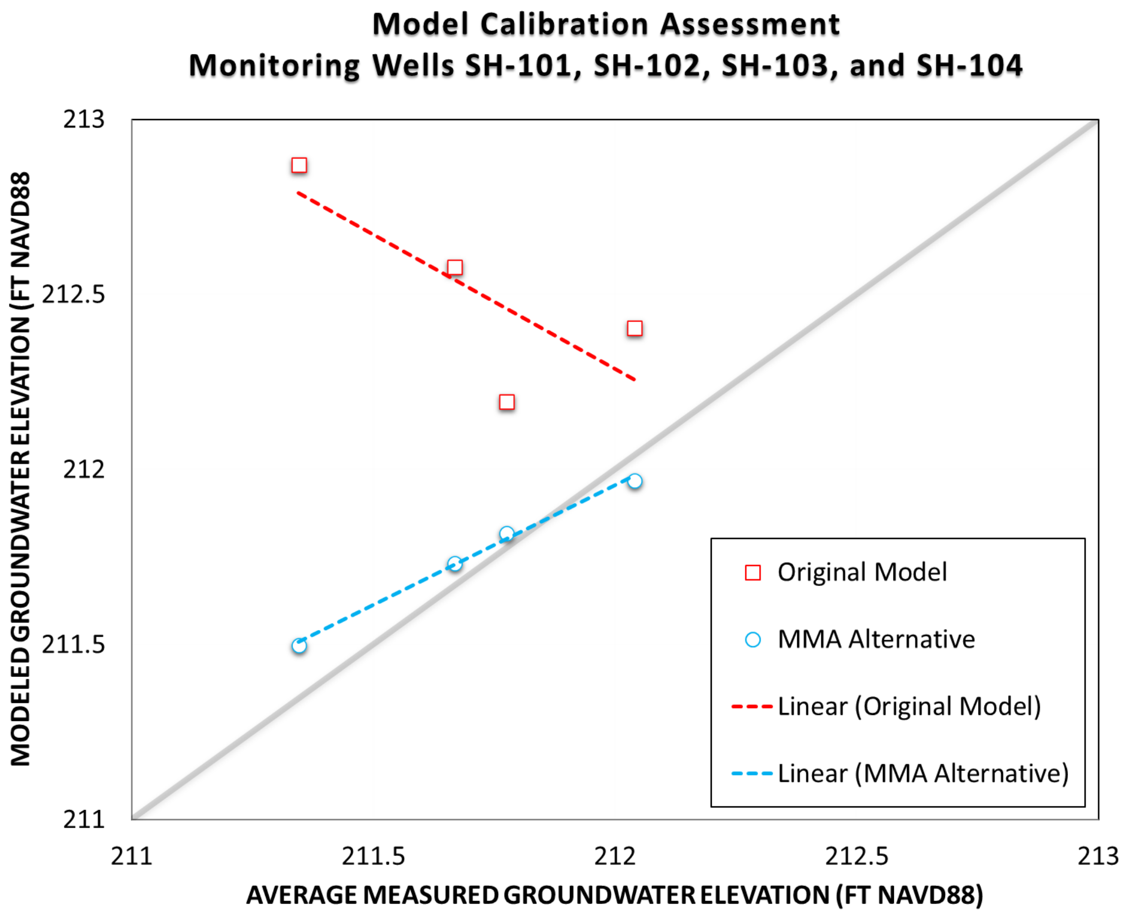
- New calibration simulations were performed to refine values of the conductance parameters associated with the head-dependent boundaries representing the northern stream and the stream-and-wetland complex to the east. Manual and automated parameter estimation calibration techniques were used, with the goal of the calibration effort being to minimize the difference between measured and modeled groundwater elevations at the four monitoring wells located on-site. The average measured groundwater elevation at each location was used in an effort to be consistent with the original calibration effort[5].

- Following calibration, a transient simulation was performed in which the rate associated with the primary wastewater disposal area was corrected to 80 percent of the proposed design flow rate in accordance with applicable MassDEP guidance. Though the original model contains a low hydraulic conductivity zone apparently intended to represent a proposed foundation wall, testing suggested limited sensitivity to explicit representation of the combined foundation wall and drain system noted on page 8 of the SHA Hydrogeo Report; therefore, these features were excluded from alternative model simulations.

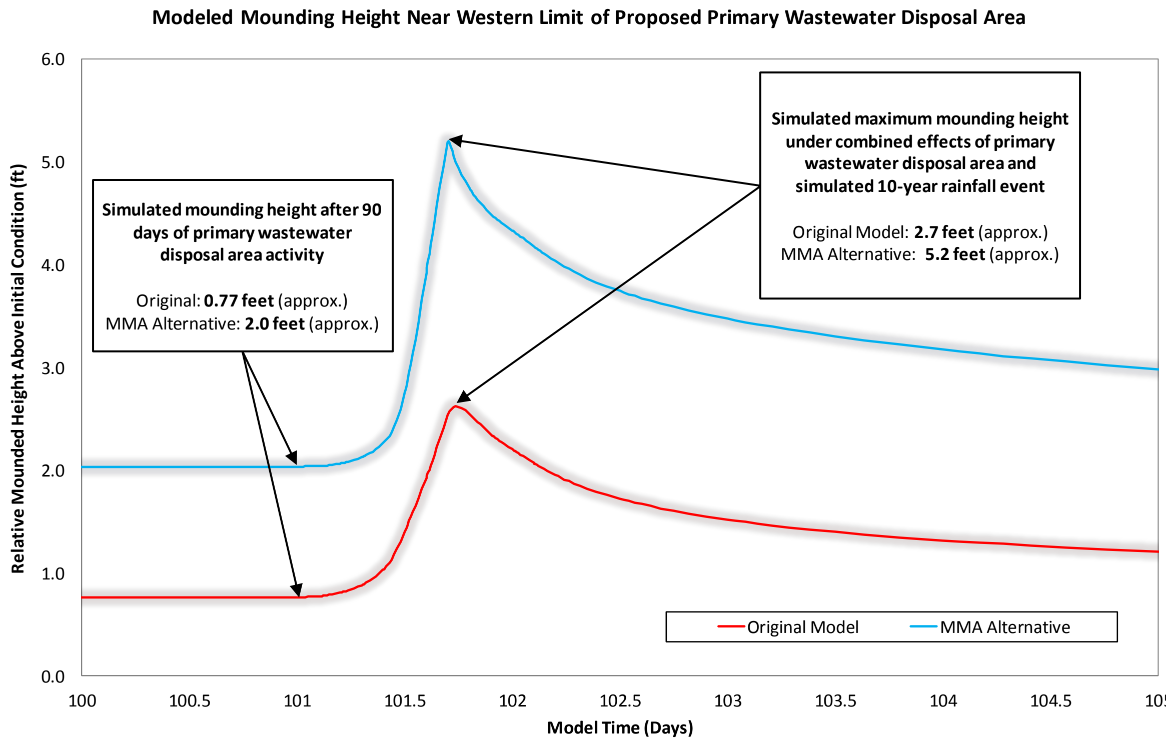
Aside from the differences noted above, MMA's alternative model mimics the structure and key parameter assignments used in the original model (i.e., hydraulic conductivity values for the two soil types, the assigned rate of precipitation recharge, the temporal discretization and time stepping structure, the simulated rate of stormwater infiltration during the 10-year rainfall event, etc.).

[5] Confirmed via email by Vern Kokosa of Sanborn Head Associates, Inc., November 11, 2020.

Two key results are derived by comparing results derived from the original model to those derived from MMA's alternative model. Firstly, it is evident that a more conceptually reasonable set of boundary conditions results in significant improvement in the match between measured and modeled groundwater elevations at the monitoring well locations. The following figure makes this improvement clear in showing comparisons between the original model (red points with red-dashed linear regression line), the MMA alternative model (blue points with blue-dashed linear regression line) and a perfect match between measured and modeled conditions (1:1 line shown in gray):



Finally, by comparing the results derived from transient simulations representative of the proposed primary wastewater disposal area, it is clear that Category 1 issues contribute significantly to low bias in mounding simulated by the original model. The following figure highlights the difference occurring at the time where mounding heights peak in both simulations:



As identified in the figure, the original model results are consistent with the 2.7 feet of simulated mounding referenced on page 9 of the SHA Hydrogeo Report (location noted to be near the upgradient southern extent of the proposed primary wastewater disposal area). However, when the same scenario is simulated with the alternative model developed by MMA, the resultant peak mounding height doubles to more than 5 feet.

Category 2

MMA defines Category 2 issues as aspects of the original model that appear to be conceptually flawed or erroneous. However, unlike Category 1 issues, information is not currently available to support a direct assessment of sensitivity via an alternative model representation. Therefore, MMA is highlighting the observed issues as areas of concern that, in our opinion, warrant additional consideration and explanation by the applicant.

Issue 2-A: The model does not represent all components of the proposed stormwater management design that could potentially influence the amount of hydraulic mounding occurring in the vicinity of the proposed wastewater disposal areas.

Transient simulations performed using the original model were intended to represent combined effect hydraulic loading from the proposed wastewater and stormwater systems. Thus, it would be important to represent any feature of the proposed stormwater system that might contribute to hydraulic mounding in key areas of concern, such as the vicinity of the proposed primary wastewater disposal area.

Based on the information contained within the Tetra Tech Stormwater Report, it appears that contributions from only 2 of the 10 proposed recharge areas were represented within the MODFLOW mounding simulations performed with the original model. Considering the peak exfiltration rates modeled by HydroCAD under the 10-year rainfall event (i.e., the considered condition within the MODFLOW simulations), the following table indicates this omission ignores approximately 50% of the event flow:

Recharge Area ID	HydroCAD Peak Flow 10-Year Rainfall Event (cubic feet per second)
1P	0.17
2P	0.35
3P	1.13
4P	0.67
5aP	0.16
5bP	0.12
5cP	0.08
5dP	0.66
5eP	0.19
5fP	0.07
Represented Total (3P, 4P)	1.8
Omitted Total	1.8

Though some of these areas may not impact mounding estimates significantly, no information has been provided to support such an assumption.

Issue 2-B: Potentially erroneously low stormwater infiltration area flow rate specification.

Though it is not entirely clear based on the post-development system diagram provided in the Tetra Tech Stormwater Report, the features identified as ponds 3P and 4P appear to coincide with the two subsurface stormwater infiltration basins simulated within the original MODFLOW model. Pages 62 and 63 of the Tetra Tech Stormwater Report indicate that HydroCAD model output for the simulated 10-year rainfall event being routed through the proposed stormwater system. The resultant predicted peak rates of exfiltration from the basins (i.e., infiltration into the groundwater system) under these conditions are 1.13 cubic feet per second (cfs) and 0.67 cfs for 3P and 4P, respectively, as shown in the excerpts below:

Pond 3P

Discarded OutFlow Max=1.13 cfs @ 13.63 hrs HW=225.42' (Free Discharge)
↑—**2=Exfiltration** (Exfiltration Controls 1.13 cfs)

Pond 4P

Discarded OutFlow Max=0.67 cfs @ 11.94 hrs HW=216.06' (Free Discharge)
↑—**2=Exfiltration** (Exfiltration Controls 0.67 cfs)

Based on an assessment of the MODFLOW files provided to MMA, the peak specified rates of infiltration for what are interpreted to be Ponds 3P and 4P are approximately 0.64 cfs (versus 1.13 cfs, as shown above) and 0.67 cfs (consistent with 0.67 cfs, as shown above), respectively. Because hydrographs for each proposed infiltration feature are not provided within the Tetra Tech Stormwater Report, a more comprehensive comparison of infiltration rates over time could not be made. However, this discrepancy at peak discharge conditions suggests that infiltration associated with the eastern stormwater infiltration basin may be significantly underrepresented within the original MODFLOW model.

This input represents a potential inconsistency with the model description provided within the SHA Hydrogeo Report. Like the underrepresented wastewater infiltration error described under Issue 1-E, it is potentially meaningful in that lower modeled flow rates translate to less significant simulated mounding and more potential bias toward non-conservative conclusions.

Issue 2-C: The model simulates hydraulic mounding that would greatly exceed proposed final grade elevations in the vicinity of the modeled stormwater recharge areas.

In reviewing the results of the transient simulation representative of the proposed primary wastewater disposal area, MMA noted that maximum mounding heights predicted within the stormwater infiltration areas are on the order of 40 feet. Such heights would greatly exceed grade under pre- or post-development conditions. This outcome highlights a potential conceptual disconnect between the HydroCAD modeling performed to support the proposed stormwater design and the MODFLOW-based mounding analysis.

Issue 2-D: Atypically low, spatially uniform 1:1 horizontal-to-vertical hydraulic conductivity anisotropy ratio.

Hydraulic conductivities of native aquifer materials, particularly in glaciated regions, are commonly recognized as differing in magnitude directionally. Soils tend to display higher hydraulic conductivity along a generalized horizontal plane and lower hydraulic conductivities in the relative tangential, or vertical, direction. The ratio of the magnitudes of the vertical and horizontal conductivities is referred to as the anisotropy ratio.

Though it is difficult to specifically measure the anisotropy ratio in the field, common values found in literature tend to reach a maximum of approximately 0.5 (i.e., 1:2 vertical-to-horizontal ratio) for material types with similar characteristics to those represented within the model[6]. MMA's review of the provided model files indicates an anisotropy ratio of 1.0 (i.e., 1:1 vertical-to-horizontal ratio) was used without specific justification being presented.

Summary

MMA's review of the MODFLOW model described by the SHA Hydrogeo Report has highlighted the list of issues presented above. Issues for which adequate supporting information was available (Category 1) were assessed via an alternative model, which yielded a greatly improved calibration result and higher peak mounding estimates. This outcome suggests the original model, as presented in support of the pending applications, is biased low and non-conservative relative to post-development groundwater mounding potential. Other issues require additional explanation and could not be assessed via the alternative model (Category 2); however, our review of available information does not suggest this explanation, if provided, would comprehensively address all faults evident in the analysis. For these reasons, it is MMA's opinion that the model is unreliable for meeting its objective.

The opinions expressed herein by MMA are based on information made available as of the indicated transmittal date. Results of model simulations performed by MMA are intended to highlight issues identified via a technical review. The results of the review, including the alternative model described herein, are preliminary and should not be used directly to revise any design aspects, nor should they be used directly to support revisions to any permit applications.

MAM/DJM/CPS
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[6] *Groundwater Hydrology, Second Edition, 1980*. Authored by David K. Todd.